AIR-1 Notes

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Open Channel Flow

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OPEN CHANNEL FLOW

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Open Channel Flow

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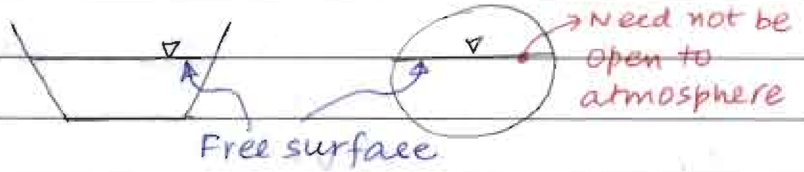
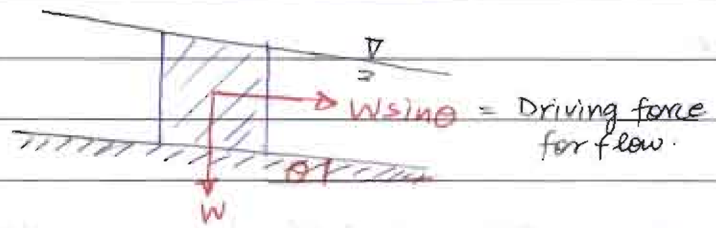
Chapter 1 - Introduction

→ Flow having free surface is called open channel flow.

→ open channel flow is due to the gravity effect.





> NOTE: On free surface, shear stress is 0.

Type of channel

- **Prismatic channel**: Channel having constant shape, size and bed slope are called prismatic channel. Generally, artificial channels like canals are prismatic
- **Non-Prismatic Channel**: Natural channels are generally Non prismatic canal.
- **Rigid Boundary Channel**: If boundary is non-deformable like- Lined canals or non-erodable unlined canal
- **Mobile Boundary Channels**: They are the ones in which boundary is deformable.

→ In rigid boundary channels, only depth of flow will vary with space and time particularly if it is prismatic.

→ The shape and roughness parameter is not a function of flow parameter

→ In mobile boundary channel, the flow carries significant amount of sediments in suspension and in contact with bed.

→ In OCF, we will study the prismatic channel.

⇒ Type of flow

Steady Flow

1. Uniform Flow
2. Gradually Varied Flow (GVF)
3. Rapidly Varied Flow (RVF)
4. Spatially Varied Flow (SVF)

Unsteady Flow

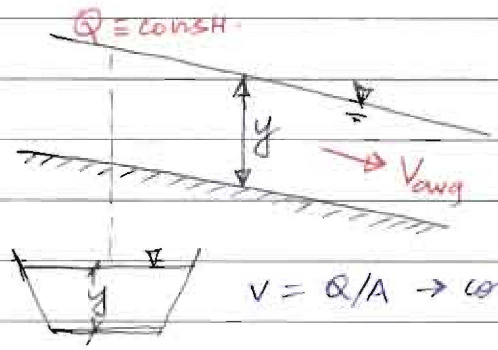
1. GVUF
2. RVUF
3. SVUF

→ If the depth of discharge changes with time, it is unsteady flow otherwise it is steady flow.

→ Steadyness or unsteadyness also depends on observers reference frame.

→ A flow may be unsteady in the inertial frame of reference but may be steady in other frame of reference.

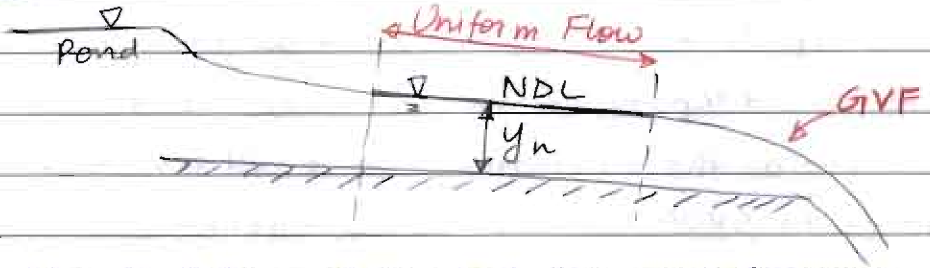
① Uniform Flow



$V = Q/A$ → constant.

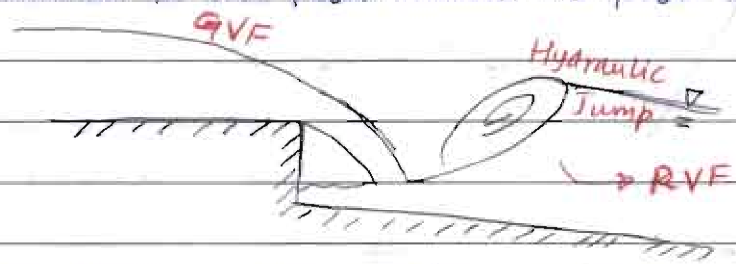
→ If in a prismatic channel, the velocity of flow and depth of flow is constant at various sections, then it is a uniform flow.

→ Depth of flow under Uniform flow is called Normal depth of flow.

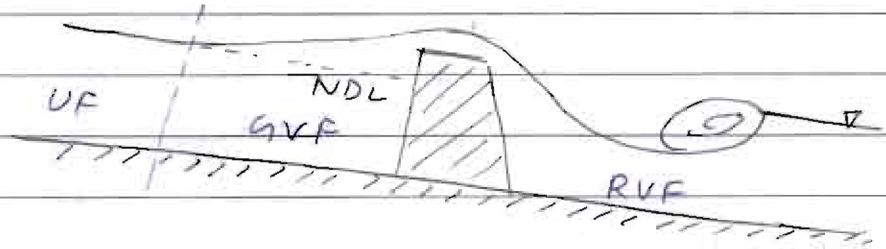


→ Any flow if left undisturbed for some distance, it tries to achieve normal depth of flow.

→ Obstruction to the flow causes the flow to vary



→ If the depth of flow varies gradually along the length of the channel it is called Gradually varied flow. But if the depth of flow varies rapidly varied flow.



→ We know that, if streamlines are straight lines, pressure variation across the depth can be taken as hydrostatic [i.e. piezometric head is constant with depth). Hence, in case of uniform flow, pressure variation across the depth can be taken as hydrostatic.

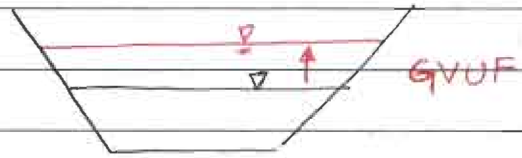
→ In case of GVF, since the streamlines are curved, normal acceleration will exist and pressure distribution truly will not be hydrostatic but since the curvature of streamline is very small in case of GVF, we can take the pressure variation to be hydrostatic, but

→ In case of RVF, since the curvature of streamline is large, pressure distribution across the depth will not be hydrostatic.

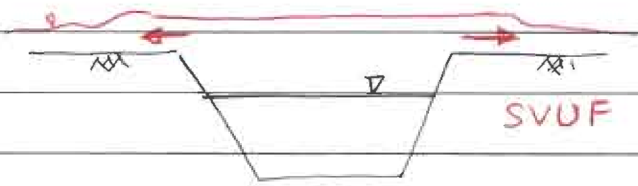
→ Since the GVF profile length is large, friction has significant effect on it but effect of friction on RVF can be neglected.

⇒ SVF – If the flow is added or extracted from the system, the flow will be called spatially varied, like infiltration from runoff. So long as the infiltration rate is not constant, flow will be termed as SVUF but once the infiltration rate becomes constant, flow can be treated as SVF.

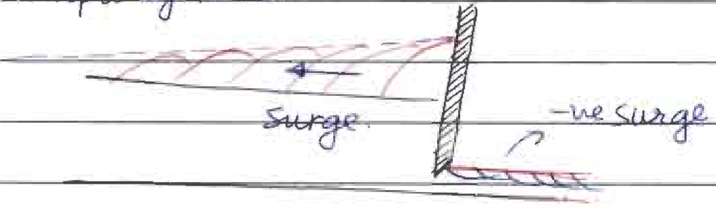
→ Passes of flood wave through a river is an example of GVUF



→ But if the river banks are breached, it is an example of SVUF



→ Surge is an example of RVUF



⇒ Laminar and Turbulent Flow

→ Reynolds no. in OCF, $R_e = \frac{VR}{\nu}$

$V \rightarrow$ average velocity

$R \rightarrow$ Hydraulic Radius = $\frac{\text{Area}}{\text{Wetted Perimeter}}$

→ If $R_e < 500$ → Flow in Open channel is laminar.

→ If $R_e > 2000$ → Flow is taken as turbulent.

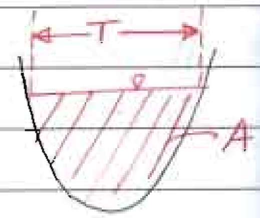
→ Generally natural channels and canals have turbulent flow.

⇒ Critical, Sub-Critical and Super critical flow

$$F_r = \frac{V}{\sqrt{gD}}$$

(V → average)

D = hydraulic Depth = $\frac{A}{T}$

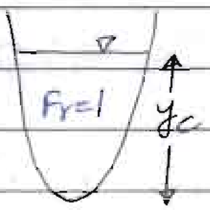


A → Area of flow

T → Top surface width

⇒ $C = \sqrt{gD}$ = celerity → velocity of small gravity wave that occurs in shallow water, generated due to disturbances (→ small) or obstacles in the channel. It is the velocity of wave wrt water and travels both upstream and downstream

$V=C$	$F_r = 1$	→ Critical flow
$V>C$	$F_r > 1$	→ Supercritical flow / Torrential / Shooting / Rapid flow
$V<C$	$F_r < 1$	→ Sub-critical flow / Tranquil flow



$F_r = 1 \rightarrow y = y_c$

$F_r < 1 \rightarrow y > y_c$

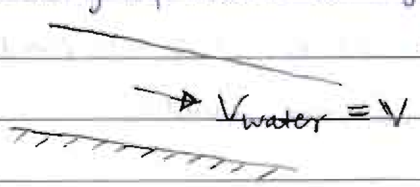
$F_r > 1 \rightarrow y < y_c$

$$F_r = \sqrt{\frac{\text{Inertial Force}}{\text{Gravitational Force}}}$$

⇒ Velocity of wave wrt ground

Velocity of wave wrt water = c [small wave in shallow water]

Velocity of wave wrt ground = $c \pm V_{water}$



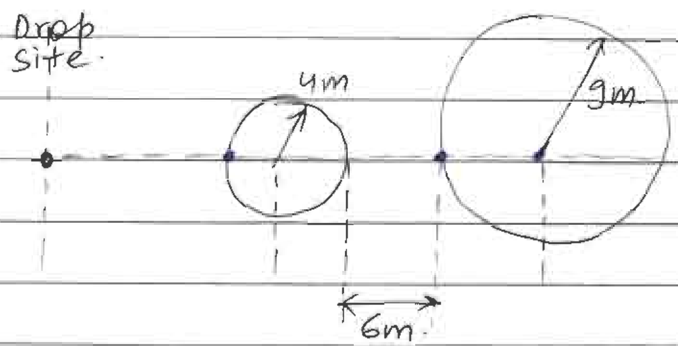
⇒ Upstream travel speed of wave = $C - V$

⇒ Downstream travel speed of wave = $C + V$

→ Under sub-critical flow conditions, since $V < C$, the small disturbance wave can travel upstream, but under super critical flow, since $V > C$, a small disturbance wave cannot travel upstream.

→ This property can be used for identifying the type of flow in field by throwing a small object, creates a ripple which travels in upstream direction also, the flow is subcritical and if does not travel upwards, the flow is supercritical.

Q- Water flows rapidly in a flat wide channel, 0.4m deep. Pebbles dropped successively in the water at the same spot creates 2 circular ripples as shown in the figure below. Find the speed of water in m/s.



$\frac{V}{\sqrt{gy}} > 1.$ $\qquad c = \sqrt{gy} = 1.98 \text{ m/s}$

$V > C$

$(V-c)(t_2-t_1) = 14$

$(V+c)(t_2-t_1) = 24$

$\frac{V-C}{V+C} = \frac{14}{24} \Rightarrow 24V - 24C = 14V + 14C$

$\Rightarrow V = \frac{38C}{10} = 7.524 \text{ m/s}$

→ Since disturbance does not travel upstream in super critical flow, it means that the flow upstream of a specified location does not know what is happening on the downstream side. In other words, to change of flow condition at a section, flow condition must be changed on the upstream side in case of super-critical flow. The super critical flow is said to have u/s control.

→ Sub critical flow is said to have down stream control.

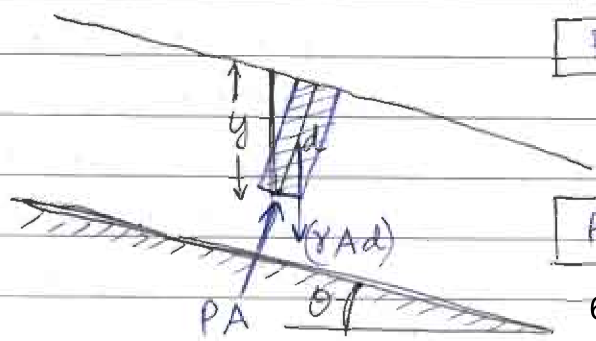
⇒ Pressure Distribution

$PA = (\gamma A d)\cos\theta$

$\boxed{P = \gamma d \cos\theta}$

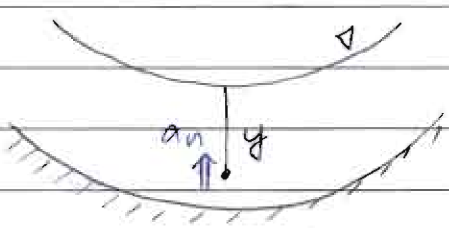
Since, $d = y\cos\theta$

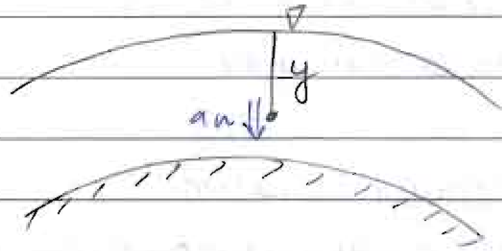
$\boxed{P = \gamma y \cos^2\theta}$



→ Generally for natural channels, $\theta < 6^\circ$ and hence pressure can be taken as γy i.e. hydrostatic pressure

→ Generally for large slopes i.e. $\theta \geq 6^\circ$, we consider the effect of θ in pressure





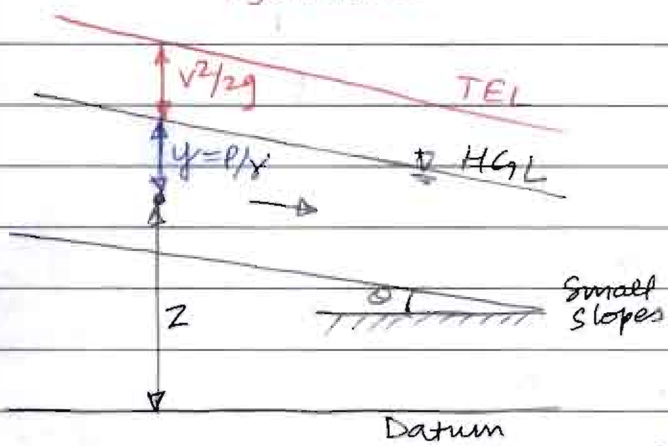
$P = \rho g_{eff} h$

$$\boxed{P = \rho (g + a_n) y}$$

↳ $P > P_{hydrostatic}$

$$\boxed{P = \rho (g - a_n) y}$$

↳ $P < P_{hydrostatic}$

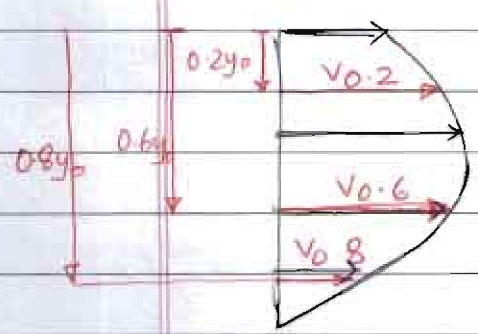


→ Generally for small slopes, HGL coincides with the free surface

$$\boxed{H_{large\ slope} = y\cos^2\theta + z + \frac{V^2}{2g}}$$

→ For large slopes, HGL lies below the free surface.

NOTE: In OCF, free surface coincides with HGL if the channel slope is small, vertical curvature of the flow lines and acceleration are negligible.

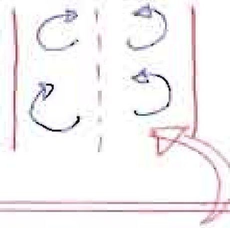


$$\boxed{V_{avg} = V_{0.6} = \frac{V_{0.2} + V_{0.8}}{2}}$$

→ V_{max} occurs slightly below the free surface

→ V_{avg} is taken as K ~~V_{avg}~~ $V_{free\ surface}$

i.e. $\boxed{V_{avg} \simeq K\, V_{free\ surface}}$ → where $K = 0.8$ to 0.95



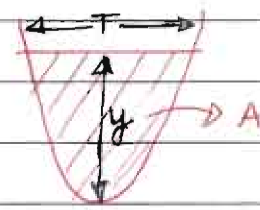
→ The dip in the flow profile is due to secondary currents.
→ Wind effects are negligible
→ if $B > 10y$ [5-10 times of y], the channel is treated as wide channel and in wide channel in the central part, the velocity dip is negligible.

⇒ Continuity Equation

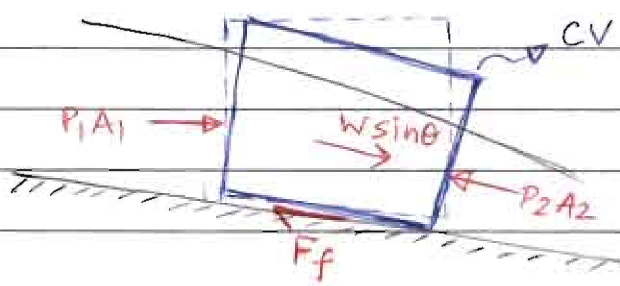
→ For steady incompressible flows, the continuity equation in open channel is taken as $\boxed{Q = \text{constant}}$ i.e. $A_1V_1 = A_2V_2$

→ For unsteady incompressible flows, the continuity equation is taken as:

$$\boxed{\frac{\partial Q}{\partial x} = -T\frac{\partial y}{\partial t}}$$



⇒ Momentum equation in OCF



$\beta_2 \approx 1$ $\beta_1 \approx 1$

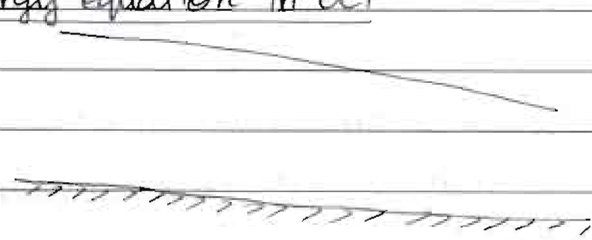
$$P_1A_1 - P_2A_2 + W\sin\theta - F_f = M_2 - M_1 = \beta_2 \rho Q V_2 - \beta_1 \rho Q V_1$$

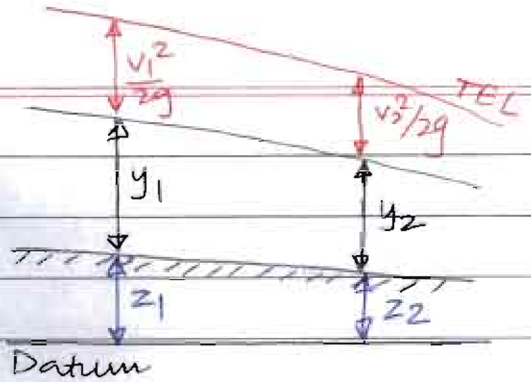
for horizontal and frictionless channel,

$$P_1 - P_2 = M_2 - M_1$$

$$\boxed{\frac{P_1 + M_1}{\gamma} = \frac{P_2 + M_2}{\gamma}} \Rightarrow \boxed{\frac{P+M}{\gamma} = \text{specific force.}}$$

⇒ Energy equation in OCF





$$\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g}\alpha_1 = \frac{P_2}{\gamma} + z_2 + \frac{v_2^2}{2g}\alpha_2 + h_L$$

$(\alpha \simeq 1)$

$$y_1 + z_1 + \frac{v_1^2}{2g} = y_2 + z_2 + \frac{v_2^2}{2g} + h_L$$

$$\text{Specific energy} = \frac{v^2}{2g} + y = E$$

→ Specific energy can be said to be the distance b/w channel bed and TEL.

NOTE: Critical Flow

→ Under critical state of flow, flow is under unstable state i.e. even a small change in the energy i.e. even a small disturbance can cause significant change in the depth of flow.

→ Water surface will appear to be wavy and unsteady.

→ Under critical condition,

① Specific energy is minimum for a given discharge.

② Discharge is maximum for a given specific energy.

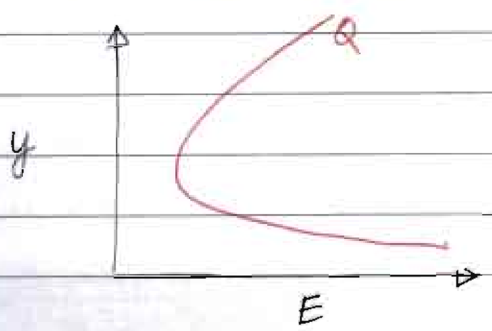
③ Specific force is minimum for a given discharge.

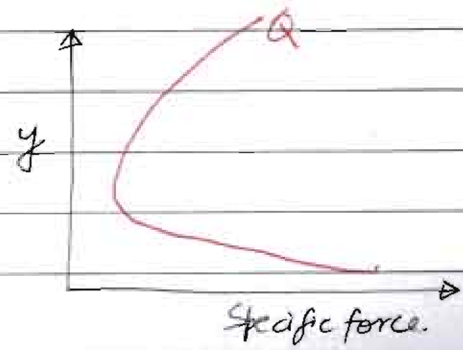
→ Froude No. = 1

✓ → Velocity head = $\frac{1}{2} \times$ (hydraulic depth) $\left[\frac{v^2}{gD} = 1 \Rightarrow \frac{v^2}{2g} = \frac{D}{2}\right]$

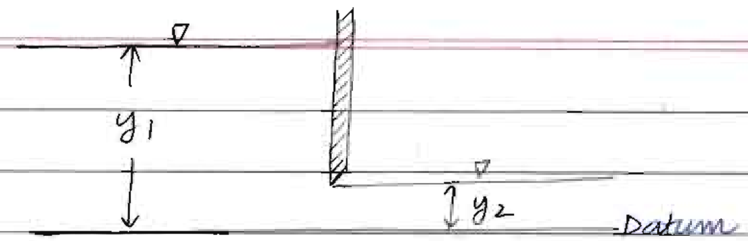
→ Velocity of flow in channel of small slope with uniform velocity distribution equals celerity (c) of small gravity wave in shallow water caused by local disturbances.

→ Slight change in ~~depth~~ energy causes significant change in depth of flow

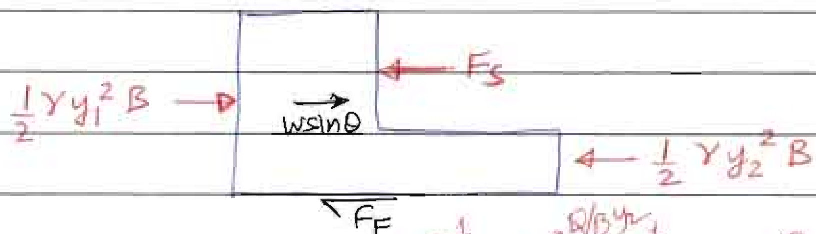




Q.



Find the force exerted by water on the sluice gate assuming negligible losses.



$$\frac{1}{2}\gamma(y_1^2-y_2^2)B - F_S = \beta_2 \rho Q V_2 - \beta_1 \rho Q V_1$$

($\beta_2 = 1$, $V_2 = Q/By_2$, $\beta_1 = 1$, $V_1 = \frac{Q}{By_1}$)

$$F_S = \frac{B\gamma(y_1^2-y_2^2)}{2} + \frac{\rho Q^2}{B}\left(\frac{1}{y_1}-\frac{1}{y_2}\right)$$

Now, applying energy eq^n

$$y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$$

$$\frac{Q^2}{2gB^2} = \frac{y_1-y_2}{\frac{1}{y_2^2}-\frac{1}{y_1^2}} = \frac{y_1^2 y_2^2}{y_1+y_2}$$

$$F_S = \frac{B\rho g(y_1^2-y_2^2)}{2} + 2\rho g B\left(\frac{y_1^2 y_2^2}{y_1+y_2}\right)\left(\frac{1}{y_1}-\frac{1}{y_2}\right)$$

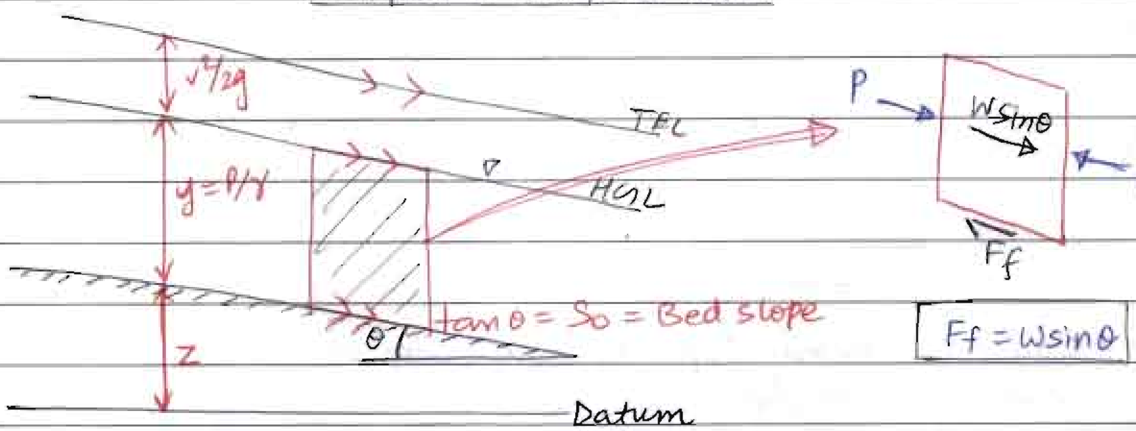
$$\frac{F_S}{B} = \frac{\gamma_w}{2}\quad y_1^2-y_2^2 + 4\frac{y_1^2 y_2^2}{y_1+y_2}\left(\frac{y_2-y_1}{y_1 y_2}\right)$$

$$\frac{F_S}{B} = \frac{\gamma_w}{2}(y_1-y_2)\left[y_1+y_2 - \frac{4y_1y_2}{y_1+y_2}\right]$$

$$\boxed{\frac{F_S}{B} = \frac{\gamma_w}{2}\frac{(y_1-y_2)^3}{y_1+y_2}}$$

NOTE: If we have the discharge given in the above problem then we should not use the formula for force per unit width as given above

Chapter-2 Uniform Flow



→ If the depth of flow, velocity of flow remains constant along the channel length, then the flow is said to be uniform.

→ velocity of flow can vary along the depth but velocity profile at every section will remain same.

→ For establishment of uniform flow certain length is required as transitiony zone. If the length of channel is less than the transitory zone length, uniform flow will not get established.

→ In case of uniform flow since the velocity is not changing, the weight component in the direction of flow must be balanced by the frictional force.

→ The constant depth of flow under uniform flow is called normal depth of flow (y_n). Any flow if left undisturbed for sufficiently long distance, it will try to achieve, the normal depth of flow.

→ Under uniform flow condition, since y and v are constant, the total energy line, the water surface line & bed of the channel will all be parallel, Hence, $S_f = S_0$ (S_f is the energy line slope)

$$Q = \frac{1}{n} A R^{2/3} S_f^{1/2} = \frac{1}{n} A R^{2/3} S_0^{1/2}$$ ⇒ Manning's Equation

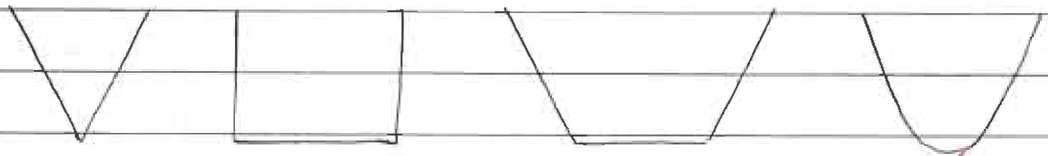
$$Q = CA\sqrt{RS_f} = CA\sqrt{RS_0}$$ ⇒ Chezy's Equation.

↳ Since, in uniform flow, $S_f = S_0$.

$$\frac{Qn}{\sqrt{S_0}} = R^{2/3} A \Rightarrow \boxed{\frac{Qn}{\sqrt{S_0}} = AR^{2/3}}$$

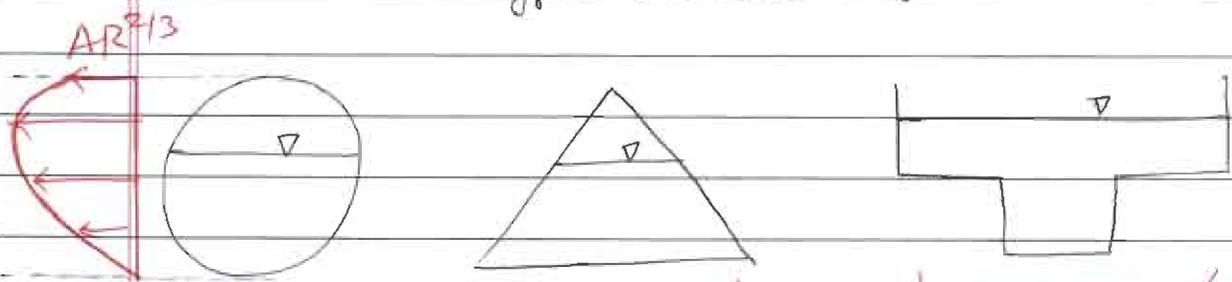
$AR^{2/3} \rightarrow f(y)$

→ Depth of flow obtained from this equation is $y = y_n$ i.e. normal depth of flow.



Only one normal depth of flow for a fixed Q, n, So.

↳ Type 1 channel (Regular channels)



There can be more than one depth for which the flow is uniform, for fixed Q, n, So

↳ Type 2 channel

Irregular Geometry

① Type 1 channel – Top surface width is increasing or remains constant with increasing depth.

② Type 2 channel – Top surface width is decreasing with increasing depth.

> NOTE: $AR^{2/3}$ increases with increase in depth of flow for type 1 channels but for Type 2 channels it increases and then decreases.

→ If n and So are known, there is only one discharge possible for uniform flow.

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→ Value of chezy's constant is $C = \sqrt{\frac{8g}{f}}$

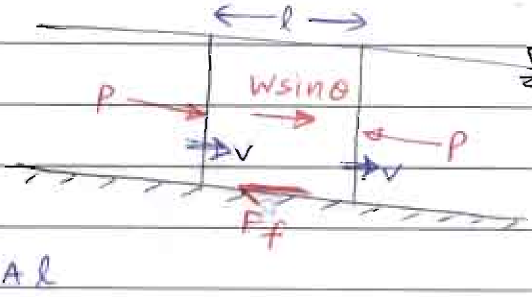
$f \rightarrow$ Darcy weischback friction factor.

→ Manning's n can be written as $n = (n_b + n_1 + n_2 + n_3 + n_4)m$

$n_b \rightarrow$ base value for straight, uniform and smooth channel
$n_1 \rightarrow$ depends on surface irregularity
$n_2 \rightarrow$ depends on shape and size of X-section
$n_3 \rightarrow$ depends on obstruction
$n_4 \rightarrow$ depends on vegetation
$m \rightarrow$ depends on meandering of channel

→ For lined canals, value of n ranges b/w 0.011 to 0.016
For natural channels, value of n ranges b/w 0.025 to 0.050

→ Momentum equation for uniform flow



$P - P + W\sin\theta - F_f = \rho QV - \rho QV$

$F_f = W\sin\theta$

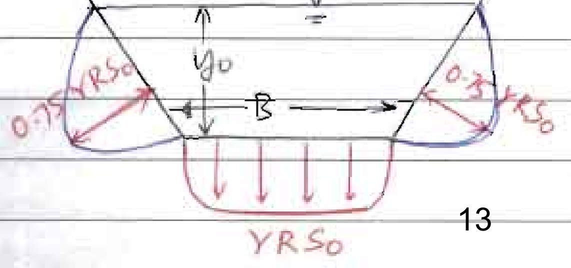
$W = \gamma A l$

$F_f = \tau_{bed} \times P \times l$

As θ is very small, $\sin\theta \simeq \tan\theta = S_0$

So, $\tau_{bed} = \frac{\gamma A l S_0}{P l} = \gamma R S_0 \Rightarrow$ $\tau_{bed} = \gamma R S_0$

↳ Average shear on the bed.



Valid for $B > 6y_0$